GeoSTAR: Developing A New Payload for GOES Satellites

Bjorn Lambrigtsen
Shannon Brown, Todd Gaier, Pekka Kangaslahti, Alan Tanner, William Wilson
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
818-354-8932
lambrigtsen@jpl.nasa.gov

Abstract—The Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) is a new concept for a microwave sounder, intended to be deployed on NOAA's next generation of geostationary weather satellites, the GOES-R series – due to first launch in 2012. This will fill a serious gap in our remote sensing capabilities of long standing – a key capability that NOAA is book keeping at the top of its list of "pre-planned product improvements" for GOES-R – i.e. the most urgently needed additional payload, which will be added as soon as funding has been allocated and programmatic issues resolved. Although real-aperture GEO microwave sounders have been proposed over the years, only GeoSTAR is capable of meeting the measurement requirements and is therefore now the leading candidate. A ground based prototype has been developed at the Jet Propulsion Laboratory, under NASA Instrument Incubator Program sponsorship, and is currently undergoing tests and performance characterization. Initial tests have been very successful, and images of the sun transiting through the field of view – the first successful imaging using a 2D aperture synthesis system and in effect constituting proof of concept – demonstrate that the system is very stable and that aperture synthesis is a feasible approach. The initial space version of GeoSTAR will have performance characteristics similar to those of microwave sounders currently operating on polar orbiting environmental satellites, but subsequent versions will significantly outperform those systems. In addition to all-weather temperature and humidity soundings, GeoSTAR will provide continuous rain mapping, tropospheric wind profiling and real time storm tracking. With the aperture synthesis approach used by GeoSTAR it is possible to achieve very high spatial resolutions without having to deploy the impractically large parabolic reflector antenna that is required with the conventional approach. GeoSTAR therefore offers both a feasible way of getting a microwave sounder with adequate spatial resolution in GEO as well as a clear upgrade path to meet future requirements. GeoSTAR offers a number of other advantages over real-aperture systems as well, such as 2D spatial coverage without mechanical scanning, system robustness and fault tolerance, operational flexibility, high quality beam formation, and open ended performance expandability. The technology and system design required for GeoSTAR are rapidly maturing, and it is expected that a space demonstration mission can be developed before the first GOES-R launch. GeoSTAR will be ready for operational deployment 2-3 years after that. Although the GeoSTAR team has been closely collaborating with the NOAA Office of System Development, which is responsible for overseeing the development of GOES-R, there are programmatic barriers that make it difficult for NOAA to develop new-technology payloads. Traditionally this has been the role of NASA, and both organizations are working on finding ways to implement this "research to operations" model without negatively impacting their other objectives. GeoSTAR is a good candidate for this model, and it is expected to go forward as a space mission within the next decade.

1. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) has for many years operated two weather satellite systems, the Polar-orbiting Operational Environmental Satellite system (POES), using low-earth orbiting (LEO) satellites, and the Geostationary Operational Environmental Satellite system (GOES), using geostationary earth orbiting (GEO) satellites. Similar systems are also operated by other nations. The POES satellites have been equipped with both infrared (IR) and microwave (MW) atmospheric sounders, which together make it possible to determine the vertical distribution of temperature and humidity in the troposphere even under cloudy conditions. Such satellite observations have had a significant impact on weather forecasting accuracy, especially in regions where in situ observations are sparse, such as in the southern oceans. In contrast, the GOES satellites have only been equipped with IR sounders, since it has not been feasible to build the large aperture system required to achieve sufficient spatial resolution for a MW sounder in GEO. As a result, and since clouds are almost completely opaque at infrared wavelengths, GOES soundings can only be obtained in cloud free areas and in the less important upper atmosphere, above the cloud tops (i.e. less important in a weather context). This has hindered the effective use of GOES data in numerical weather

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prediction. Full sounding capabilities with the GOES system is highly desirable because of the advantageous spatial and temporal coverage that is possible from GEO. While POES satellites provide coverage in relatively narrow swaths, and with a revisit time of 12-24 hours or more, GOES satellites can provide continuous hemispheric or regional coverage, making it possible to monitor highly dynamic phenomena such as hurricanes. Such observations are also important for climate and atmospheric process studies.

In response to a 2002 NASA Research Announcement calling for proposals to develop technology to enable new observational capabilities from geostationary orbits, the Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) was proposed as a solution to the GOES MW sounder problem. Based on a concept first developed at the Jet Propulsion Laboratory in 1998 and intended for the NASA New Millennium EO-3 mission, GeoSTAR synthesizes a large aperture to measure the atmospheric parameters at microwave frequencies with high spatial resolution from GEO without requiring the very large and massive dish antenna of a real-aperture system. With sponsorship by the NASA Instrument Incubator Program (IIP), an effort is currently under way at the Jet Propulsion Laboratory to develop the required technology and demonstrate the feasibility of the synthetic aperture approach – in the form of a small ground based prototype. This is being done jointly with collaborators at the NASA Goddard Space Flight Center and the University of Michigan and in consultation with personnel from the NOAA/NESDIS Office of System Development. The objectives are to reduce technology risk for future space implementations as well as to demonstrate the measurement concept, test performance, evaluate the calibration approach, and assess measurement accuracy. When this risk reduction effort is completed, a space based GeoSTAR program can be initiated, which will for the first time provide MW temperature and water vapor soundings as well as rain mapping from GEO, with the same measurement accuracy and spatial resolution as is now available from LEO – i.e. 50 km or better for temperature and 25 km or better for water vapor and rain. Furthermore, the GeoSTAR concept makes it feasible to expand those capabilities without limit, to meet future measurement needs.

The GeoSTAR prototype has now been completed, and tests are under way to assess its performance. Results so far are excellent, and this development can now be characterized as proof of the aperture synthesis concept. This constitutes a major breakthrough in remote sensing capabilities. Further technology development is under way, both as risk reduction and to enhance the measurement capabilities of the GeoSTAR system. At the same time, efforts are also under way to identify sponsorship and secure funding for a space demonstration mission in the 2012-2015 time frame. It is likely that a GeoSTAR mission will be a joint NASA-NOAA undertaking, which increases the programmatic complexity, and many issues remain to be resolved.

2. Functionality and Performance Requirements

In developing the GeoSTAR technology and prototype a notional space system performing at the same level as the Advanced Microwave Sounding Unit (AMSU) system now operating on NASA and NOAA polar-orbiting LEO satellites was used for design and sizing purposes. The notional operational GeoSTAR will provide temperature soundings in the 50-60 GHz band with a horizontal spatial resolution of 50 km and water vapor soundings and rain mapping in the 183-GHz band with a spatial resolution of 25 km. A possible third band would operate in the 90-GHz window region (and would possibly also cover the 118-GHz oxygen line for additional information about clouds). Radiometric sensitivity will be better than 1 K in all channels. These are considered to be the minimum performance requirements, but the first space implementation could be built to exceed this minimum performance. It should be emphasized that it is necessary to operate in these bands in order to provide soundings to the surface. Others have proposed building sounding systems operating at higher frequencies, where an adequate spatial resolution can be attained with a smaller aperture (and thus could be implemented as a real-aperture system), but since the opacity of a moist atmosphere increases sharply with frequency, as illustrated in Fig. 1, it is not possible to reach the surface under all conditions at those higher frequencies. In particular, moist and cloudy tropical conditions, such as encountered in the tropical cyclones that are of paramount interest, can only be fully sounded in the 50- and 183-GHz bands.

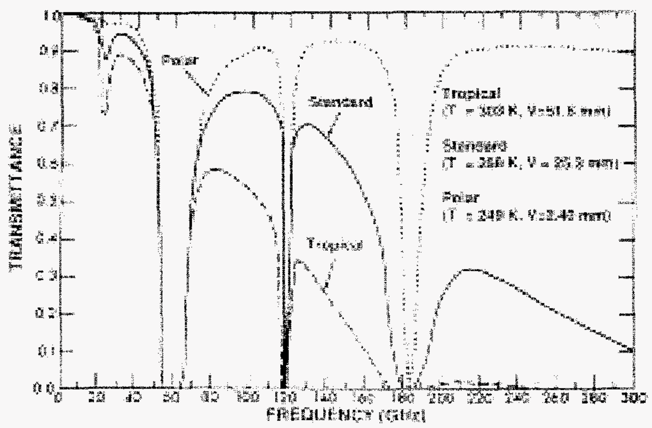


Figure 1 - Atmospheric transmittance in MW bands (From Grody in [1])

With the notional GeoSTAR system, it will be possible to produce temperature soundings within the troposphere for most of the visible Earth disc (out to an incidence angle of 60° or more) with a 2-4 km vertical resolution every 30 minutes and humidity soundings with a vertical resolution of 3-4 km every 5-10 minutes. GeoSTAR is a non-scanning 2D imaging system. These soundings are obtained everywhere at the same time – i.e. there is no time lag between different portions of the scene as there is in a mechanically scanned system. That also makes this system ideal for derivation of wind profiles through tracking of water vapor features – although the vertical resolution is limited. GeoSTAR produces several 2D "snapshots" every seconds. These images are combined over longer time periods to produce low-noise radiometric images that are then used for geophysical "retrievals" or directly assimilated into forecast models. It is also possible to recover temporal information at a much higher resolution than the "averaging window" of 30 minutes (in the case of temperature soundings), and this can be exploited when rapidly evolving processes need to be resolved more precisely. The retrieval of vertical profiles of temperature, water vapor density and liquid density from spectrally sampled brightness temperatures is well established (see, e.g., [1]), and such profiles are routinely derived from AMSU observations. These methods will also be used with GeoSTAR.

In addition to atmospheric profiles GeoSTAR will also be used to measure precipitation. There are two approaches for this, both depending on scattering. The first method is one developed by Ferraro and Grody [2], which uses window channels at 89 and 150 GHz to measure the scattering caused by ice particles formed in and above rain cells. This method may be adapted to use a 50-GHz window channel in lieu of 89 GHz. A second approach has been developed by Chen and Staelin [3] and uses a number of channels in the 50-GHz band and the 183-GHz band to derive precipitation estimates – this is also based on the ice scattering signature. Although there are limitations with these methods (some stratiform and warm rain conditions are problematic), GeoSTAR offers the advantage of continuous full-disc coverage and can therefore be used to fill in the gaps between the narrow swaths of LEO-based systems. In addition, frozen precipitation (snow), which is difficult to detect by conventional means, can also be observed with these methods. These capabilities will be used to complement the observations obtained from the planned Global Precipitation Mission and its successors.

3. Instrument Concept

As illustrated schematically in Fig. 2, GeoSTAR consists of a Y-array of microwave receivers, where three densely packed linear arrays are offset 120° from each other. Each receiver is operated in I/Q heterodyne mode (i.e. each receiver generates both a real and an imaginary IF signal). All of the antennas are pointed in the same direction. A digital subsystem computes cross-correlations between the IF signals of all receivers simultaneously, and complex cross-correlations are formed between all possible pairs of antennas in the array. In the small-scale example of Fig. 2 there are 24 antennas and 276 complex correlations (=24*23/2). Accounting for conjugate symmetry and redundant spacings, there are 384 unique so-called uv-samples in this case. Each correlator and antenna pair forms an interferometer, which measures a particular spatial harmonic of the brightness temperature image across the field of view (FOV). The spatial harmonic depends on the spacing between the antennas and the wavelength of the radiation being measured. As a function of antenna spacing, the complex cross-correlation measured by an interferometer is called the visibility function. This 2-dimansional function is essentially the Fourier transform of the function of brightness temperature versus the incidence and azimuth angles (or, direction cosines). By sampling the visibility over a range of spacings and azimuth directions one can reconstruct, or "synthesize," an image in a computer by discrete Fourier transform. These techniques are well known in radio astronomy, but are relatively new to earth remote sensing problems. Thus, in Fig. 2, the left panel shows the distribution of receivers in the instrument's aperture plane,

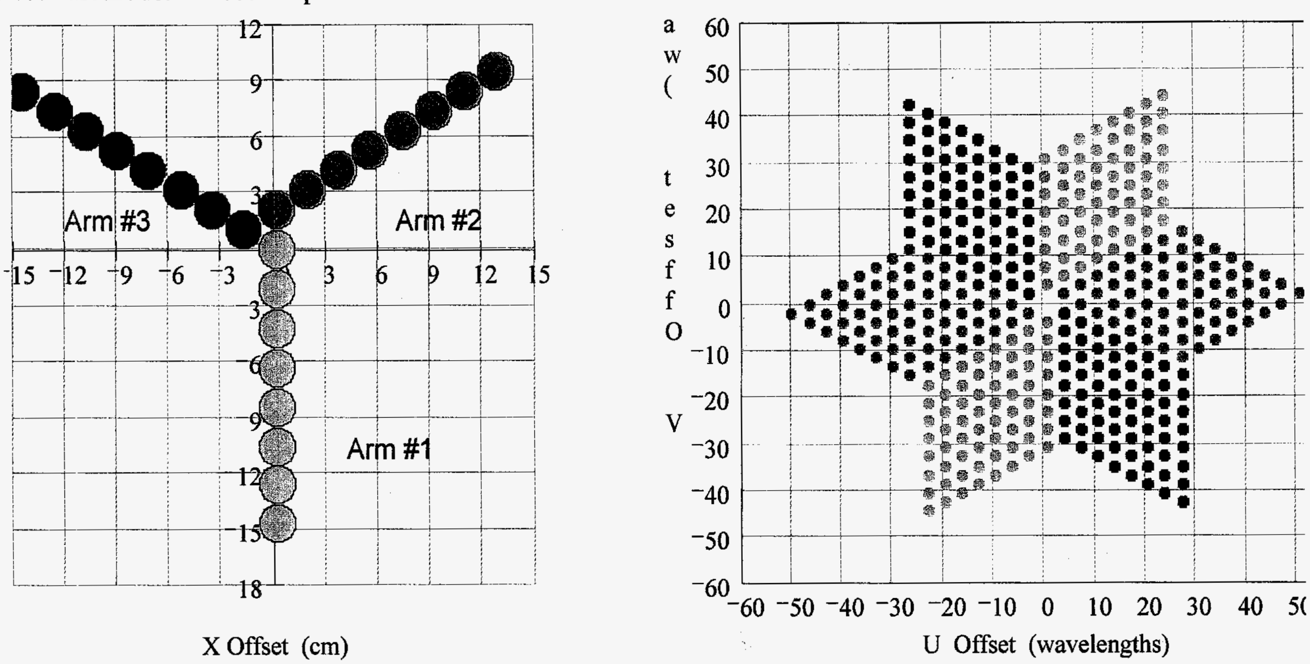


Figure 2 - Antenna array (left) and uv sampling pattern (right), as implemented in the GeoSTAR prototype

and the right panel shows the resulting sampling points in spatial Fourier space i.e. in terms of spatial harmonics).

The "Y" configuration of the GeoSTAR array is motivated by the need to measure a complete set of visibility samples with a minimum number of antennas. In principle, one can measure the visibility function with just two antennas by mechanically varying their spacing and orientation. But this is not practical for the present application, and would require too much observation time for the sequential measurements. Instead, GeoSTAR uses a thinned (or "sparse") array to simultaneously measure all the required spacings from a fixed antenna geometry. There are many kinds of sparse arrays, and the "Y" array of Fig. 2 is one of the best in terms of efficient use of antennas and in terms of the simplicity of the structure - which lends itself well to a spaceborne deployment. As illustrated in Fig. 2, the spacings between the various antenna pairs yield a uniform hexagonal grid of visibility samples. By radio astronomy convention, the spacings are called the "baselines," with the dimensions "u" and "v." The primary advantage of the sparse array is that it uses far less physical antenna aperture space than the comparable real aperture.

The smallest spacing of the sample grid in Fig. 2 determines the unambiguous field of view, which for GeoSTAR must be larger than the earth disk diameter of 17.5° when viewed from GEO. This sets both the antenna spacing and diameter at about 3.5 wavelengths, or 2.1 cm at 50 GHz, for example – as illustrated in Fig. 2. The longest baseline determines the smallest spatial scale that can be resolved, which for the array in Fig. 2 is about 0.9° (i.e. ~~17.5°/√384~~). To achieve a 50 km spatial resolution at 50 GHz, a baseline of about 4 meters is required. This corresponds to approximately 100 receiving elements per array arm, or a total of about 300 elements. This in turn results in about 30,000 unique baselines, 60,000 uv sampling points (given conjugate symmetry), and therefore 60,000 independent pixels in the reconstructed brightness temperature image, each with an effective diameter of about 0.07° - about 45 km from GEO.

4. PROTOTYPE

A small-scale prototype has been built to address the major technical challenges facing GeoSTAR. These challenges are centered around the issues of system design and calibration. (Power consumption has also been a major concern, but recent and continuing miniaturization of integrated circuit technology has demonstrated that this should no longer be seen as a major issue.) Synthesis arrays are new and untested in atmospheric remote sensing applications, and the calibration poses many new problems, including those of stabilizing and/or characterizing the phase and amplitude response of the antenna patterns and of the receivers and correlators. System requirements need to be better understood - and related to real hardware. To these ends the prototype was built with the same receiver technology, antenna design, calibration circuitry, and signal processing schemes as are envisioned for the spaceborne system. Only the number of antenna elements differ. Progress on this system has been rapid in recent months, and the following discussion will attempt to emphasize the most recent achievements at the time of writing.

The prototype consists of a small array of 24 elements operating with 4 AMSU channels between 50 and 54 GHz. Fig. 3 shows a photo of the prototype. As illustrated in both Fig. 2 and Fig. 3, there is no receiver at the exact center of the array as there would be in a fully symmetric system. A center feedhorn poses a number of unnecessary complications to the system, related to the physical package

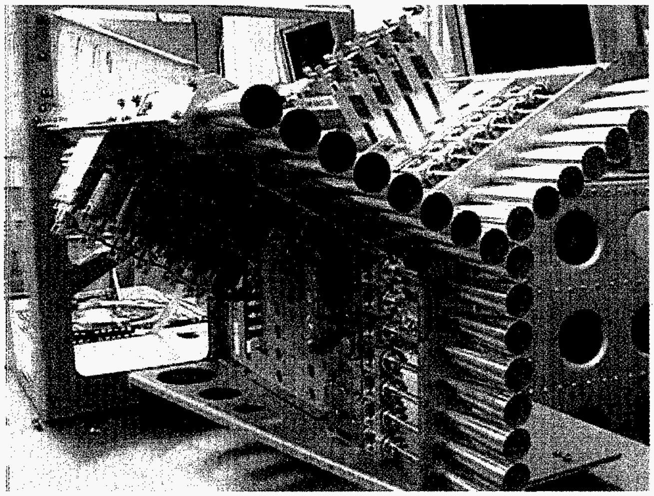


Figure 3 - GeoSTAR prototype

(there is not enough room) and the electrical design (to be discussed below). The solution is to remove the one horn, from the center of the array, stagger the three arms counter clockwise, and then bring them together so that the three innermost horns form an equilateral triangle. This staggered-Y configuration eliminates the need for an odd receiver at the center, which simplifies both mechanical and electronic design. The only penalty is a slight and negligible loss of

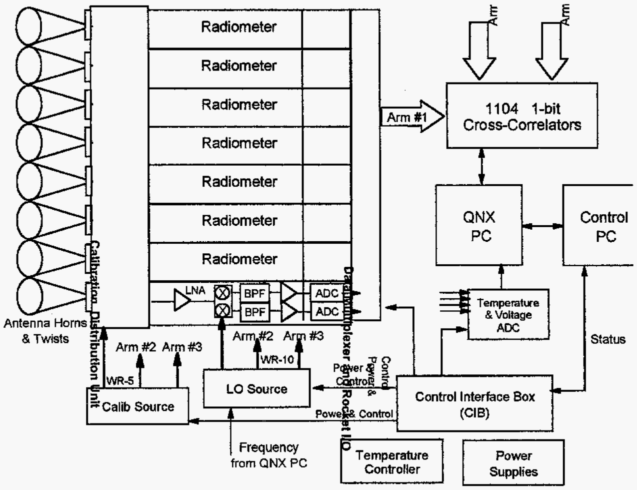


Figure 4 - Receiver system block diagram – one of three arms shown

visibility coverage.

A simplified block diagram of the GeoSTAR prototype is given in Fig. 4. From left to right in Fig. 4 - or from front to back in Fig. 3 - the signal starts at the horn aperture with a vertical polarization (say), and then passes through a waveguide twist which aligns the waveguide to the orientation of the 8-element array arm. Each of the three arms require different twists: the top two arms of Fig. 3 twist 60° in opposite directions, and the bottom arm doesn't twist at all. This results in all receivers detecting the same linear polarization, as is commonly required for sounders with channels sensitive to surface radiation (which is polarized). GeoSTAR is very sensitive to antenna pattern differences among antennas, and a waveguide twist proved to be the easiest solution to guarantee a precise polarization match.

The signal in Fig. 4 then passes through an 8-way calibration feed which periodically injects a noise signal into all receivers from a common noise diode source. This signal will be used as a reference to stabilize the system against gain, phase, and system noise drifts. The injected noise signal needs to be in the range of 1 to 10 K of equivalent noise temperature at the receiver input.

The noise diode signal is distributed to the three arms via phase shifters. Each of these phase shifters consists of a PIN diode and hybrid MMIC assembly which can switch between 0° and 120°. Correlations that occur between receivers of different arms can be excited by the noise diode with three possible phases using any two of these switches. This capability is critical to ensure that every correlator can be stabilized with respect to both phase and amplitude. Without this capability one must otherwise depend on perfect quadrature balance of the complex correlations, which is predictably not perfect. It is also worth noting that the phase of the noise diode cannot be shifted among the 8 antennas of a given arm, but that such a capability is not needed for the staggered-Y arrangement of the antennas. With the staggered-Y all correlations within an arm represent visibility samples that are redundant to samples that can otherwise be obtained between elements of different arms. These redundant correlations are not needed for image reconstruction, so they do not need to be calibrated.

Continuing the discussion of Fig. 4, the antenna signal passes into the MMIC receiver module, where it is amplified using InP FET low noise amplifiers and then double-sideband downconverted in phase quadrature by subharmonic mixers to two IF signals of 100 MHz bandwidth. The bandwidth is defined by lumped element filters. A photograph of a prototype receiver module is provided in Fig. 5. The local oscillator operates from 25 to 30 GHz, and is distributed via three phase shifters. These MMIC phase shifters periodically shift the phase of each arm by 90° (180° at RF) to provide a means of switching the correlator phase and chopping out correlator biases. Again, the staggered-Y arrangement of the array proves crucial to this function since one would otherwise need phase shifters within each arm. (This was the original plan,

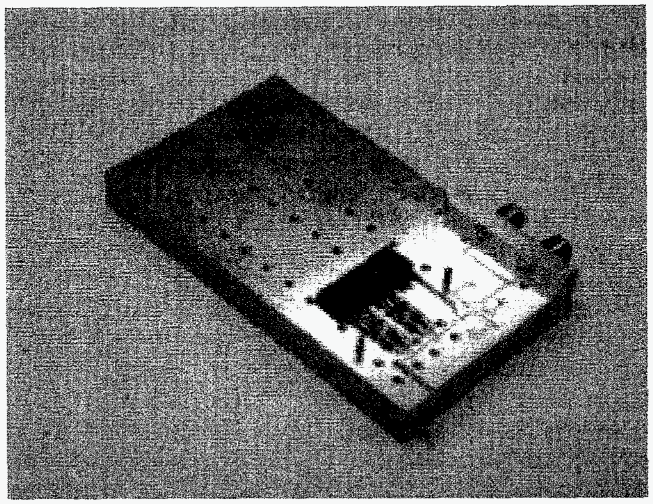


Figure 5 - Prototype receiver module (cover off)

but it proved impractical due to the timing complexity when switching phase among all 24 receivers.)

The in-phase (I) and quadrature (Q) IF signals from each receiver are then digitized at a clock rate of 110 MHz. For reasons of product availability, the analog to digital converter is presently an 8-bit device, but this could be replaced with a two-bit or possibly just a one-bit converter to save power. The correlations only require 1-bit resolution (i.e. the sign bit), and the extra bits are only used to monitor changes in system noise temperature. There is a single multiplexer for each arm of the array - the term "multiplexer" here refers to the fact that eight receivers are combined on a single digital bus for transmission to the central correlator. An FPGA performing most of the functions of the multiplexer also includes "totalizers", which are used to count the occurrences of each ADC output state so that the threshold levels can be compared with the known Gaussian statistics of the IF voltage.

Perhaps the most important subsystem is the correlator, which must perform multiplications of all 100-MHz signal pairs in real time. For a spaceborne operational system with 100 elements per arm discussed earlier, that requires on the order of 20 trillion multiplications per second. To achieve such a high processing rate with a reasonable power consumption, the correlators are implemented as 1-bit digital multiply-and-add circuits using a design developed by the University of Michigan. 1-bit correlators are commonly used in radio astronomy. The correlator for the GeoSTAR prototype, where low cost was more important than low power consumption, is implemented in FPGAs. An operational system will use low-power application specific integrated circuits (ASICs). Current state of the art would then result in a power consumption of less than 20 W for the 300-element system discussed above, and per Moore's Law this will decline rapidly in future years.

5. Early Test Results

A number of tests have already been done in a laboratory setting, and the results are very encouraging – no serious problems have been identified so far, and the system is working exactly as expected, which is a remarkable achievement. Following the laboratory tests, the system was moved outdoors to observe the sky and the sun. The array was pointed into the path of the sun, and the sun was allowed to pass through the center of the field of view at an elevation of 45°. Pictures of the basic setup are shown in Fig. 6. During these tests, the antenna fixture was disturbed several times as different sun shields (made of pieces of

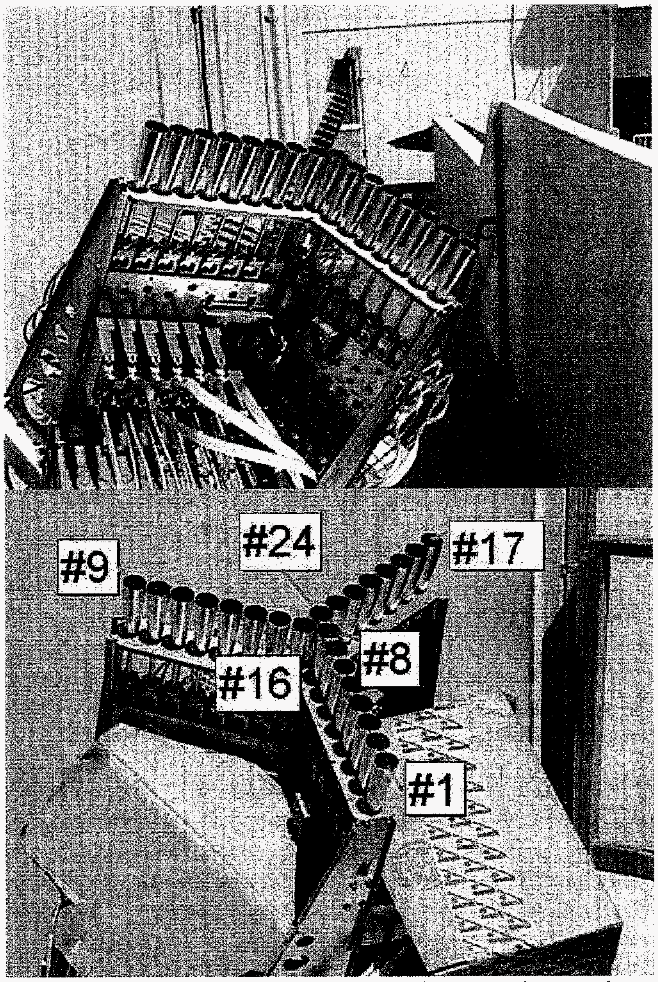
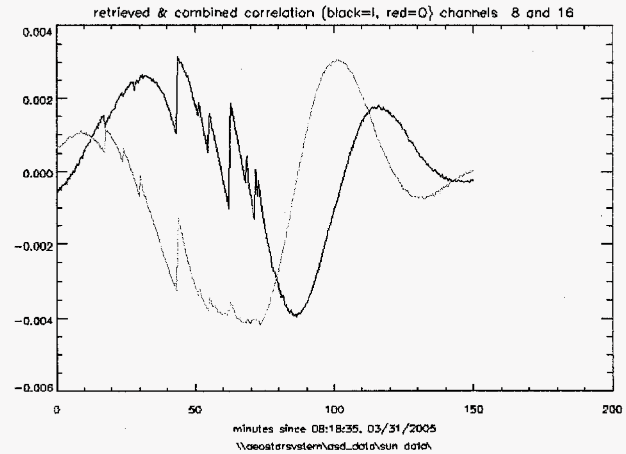


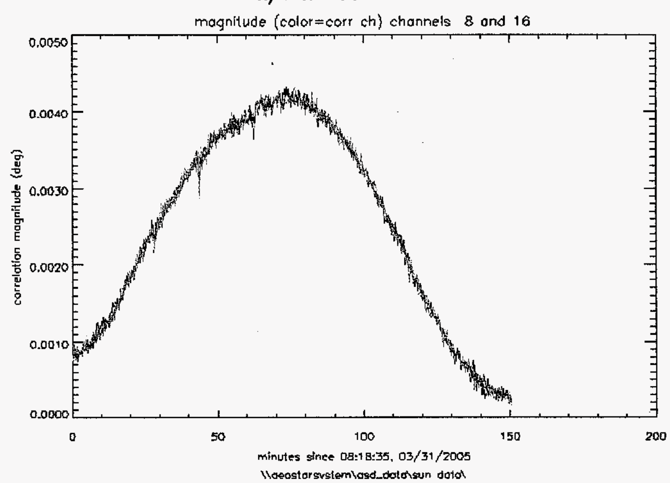
Figure 6 - GeoSTAR prototype outdoors to observe the sun's transit
a) Initial configuration (top panel); b) final (bottom panel)

cardboard) were arranged on the structure to keep the receivers from overheating in the sun, as shown. This activity resulted in several interruptions in the observations, and it is likely that the uneven temperatures of the antennas resulted in uneven receiver noise temperatures. Although none of the calibration subsystems were operated during this test (except the LO phase switching), the results were spectacular and give us confidence that both system design and performance will exceed expectations.

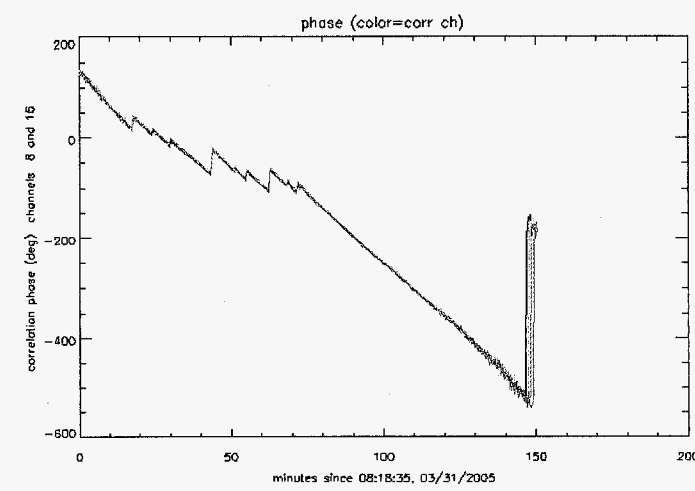
Fig. 7 shows the raw correlations and the retrieved magnitude and phase for one sample baseline during the solar transit. The amplitude curve essentially represents the elemental antenna pattern modulated by a varying atmospheric attenuation. The glitches caused by the mechanical disturbances discussed above are obvious in the



a) Raw correlations



b) Derived magnitude



c) Derived phase

Figure 7 - Sun measurements: One neighboring receiver pair near the center of the array

phase plot – and as expected for translations. Nevertheless, the results are very satisfactory and demonstrate remarkable stability.

We have done some further analysis of the solar data, and Fig. 8 shows a series of reconstructed (but uncalibrated) brightness temperature images. (An animation of the entire sequence also exists.) These images were reconstructed using the so-called G-matrix approach and accounts for the elemental antenna patterns. The most notable feature in these images is the hexagonal-symmetric sidelobe pattern. Fig. 9 shows a color coded image of this pattern (left panel), derived from the observations when the sun was near the center of the field of view as well as a line plot along a particular azimuth direction (right panel). The most notable feature here is that the pattern is indistinguishable from the theoretical "sinc" function. In particular, note that the sidelobes are both positive and negative. That makes it possible to apply simple image processing techniques to achieve an optimal balance of image sharpness (i.e. spatial

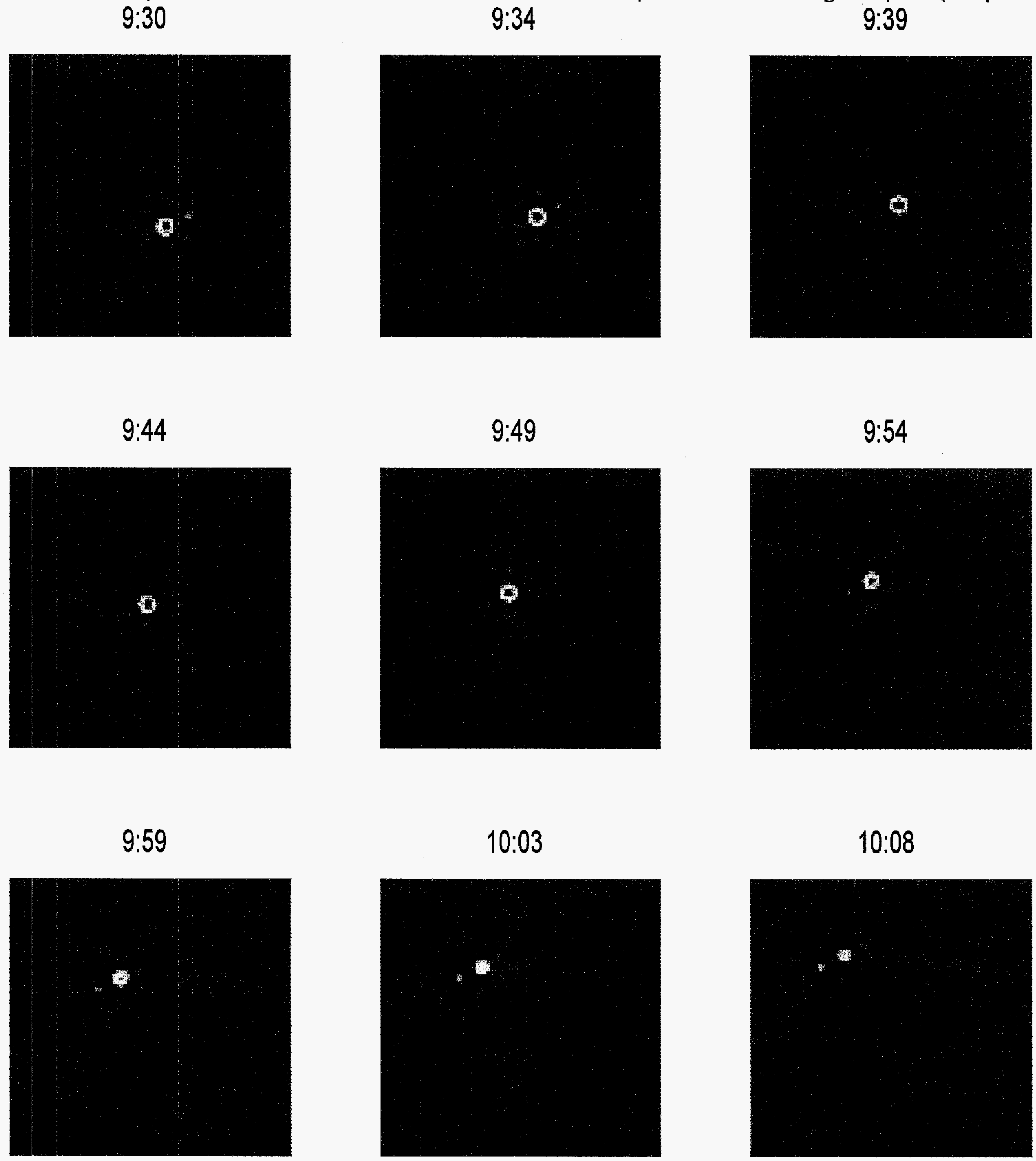


Figure 8 - GeoSTAR images of solar transit (times are in PDT)

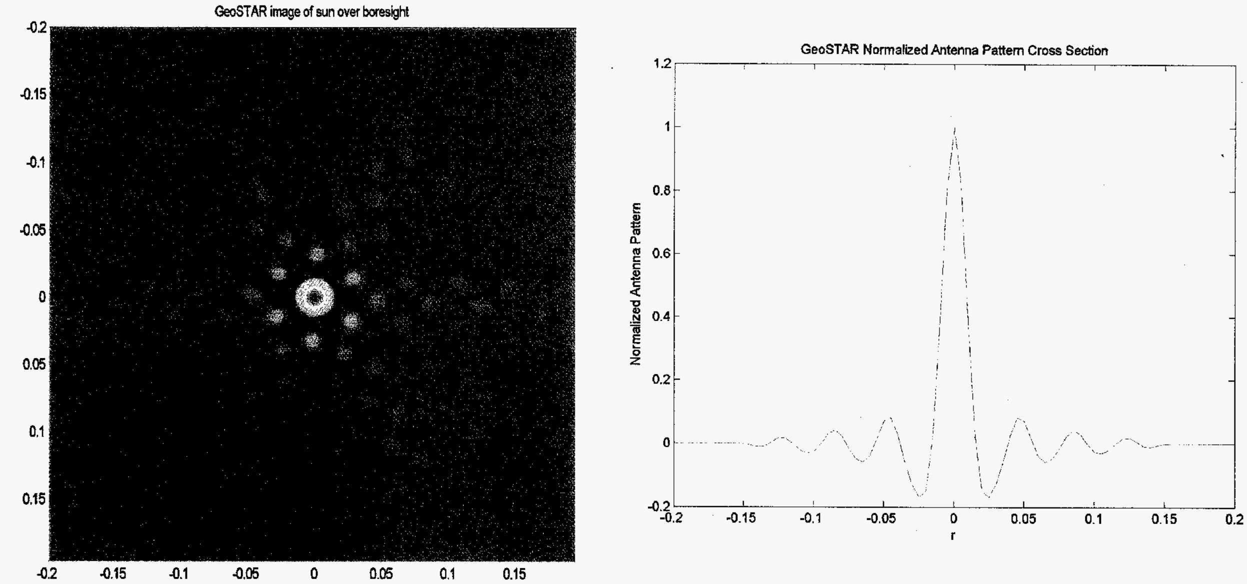


Figure 9 - GeoSTAR effective spatial resolution element (pixel) antenna pattern

resolution) and beam efficiency (i.e. effective sidelobe level). Typically, this consists of applying a "window", such as a "box-car" or a Hamming window – i.e. techniques that are well known in image processing. This is one of the most powerful features of an aperture synthesis system such as GeoSTAR.

6. Programmatic Considerations

The GeoSTAR team has worked closely with representatives from the NOAA National Environmental Satellite Data and Information Service (NESDIS) Office of System Development (OSD) since the inception of the IIP prototyping project. NASA Headquarters has also provided programmatic and scientific oversight. This has resulted in the GeoSTAR design being closely aligned with "customer" needs. The measurements that GeoSTAR will provide are needed by NOAA for operational use (i.e for assimilation into numerical weather prediction systems) and are needed as well by NASA for research use (i.e. for investigations related to the hydrologic cycle). The requirements of NOAA NESDIS are collected in the GOES-R Performance Requirements Document (GPRD), where the need for a microwave sounder is expressed in the form of one of several Pre-programmed Product Improvements (P^3I). The MW sounder P^3I is currently on top of the list, i.e. NOAA considers this to be their highest-priority unmet need. Normally, as soon as funding for such a payload has been identified and the technological maturity sufficient for an operational mission, the payload is elevated to baseline status. This has been difficult to effect in the case of GeoSTAR, however, both because of the relatively low technologic maturity level and because of the difficulty of identifying the funds required in the current budgetary environment. On the other hand, several independent reviews have concluded that the conventional approach (i.e. using a real-aperture system) will not satisfy the requirements, and GeoSTAR is now recognized as the most likely candidate to provide the missing functionality. The prototype is intended to retire some of the more stressing technology risk, and results obtained to date show that this has largely been accomplished. However, it still difficult for NOAA to fund the first GeoSTAR space mission, and it generally looks to NASA to do that. On the NASA side, science research missions tend to have higher priority than pre-operational missions (as a GeoSTAR space demonstration might be), and it has therefore been difficult also for NASA to identify funding for GeoSTAR. A promising mechanism is through the "Research-to-operations" path, which has been identified by both organizations as worthwhile. Here, NASA first develops the necessary technology, followed by a space "research" mission that demonstrates the capabilities and elevates the maturity to operational status – at which point the mission is handed over to NOAA for operational use. NOAA would subsequently procure additional copies of the payload to populate future platforms. A GeoSTAR space demonstration mission is now being discussed between NASA and NOAA, and it is likely that such a mission will be recommended. Another possible path is as a NASA research mission, such as through the Earth System Science Pathfinder (ESSP) series. Those missions generally require fairly high technologic maturity, but the ongoing GeoSTAR related technology development efforts may make such a mission plausible. A science driven GeoSTAR mission has been discussed in some detail in a white paper provided in response to the RFI issued for the NRC Decadal Survey of the NASA Earth science program that is currently under way.

The GeoSTAR IIP project will come to an end in early 2006, but as was alluded to above, several additional technology development efforts are under way, funded through the NASA Earth-Sun System Technology Office (ESTO), which also sponsors the IIP program, as well as through internal JPL development funds. It is expected that those efforts will continue, and the result will be to retire additional technology risk.

7. Summary

The GeoSTAR concept and the related technology have been maturing rapidly. The recent test results amount in effect to proof of concept, and this represents a major breakthrough in remote sensing capabilities. The continuing efforts to develop the technology further will enhance the system's performance as well as retire technology risk, and it is anticipated that the concept will be mature enough that a space mission can be implemented in the 2012-2015 time frame. The only major obstacles remaining will then be of a programmatic and budgetary nature. It is likely that those will be overcome, and so a GeoSTAR mission is likely within the next 10 years. This will add significantly to the nation's remote sensing capabilities, and the GeoSTAR observations are expected to have a significant forecast impact and will greatly benefit research related to the hydrologic cycle as well. In particular, the GeoSTAR observations will add much to our ability to observe, understand and predict severe storms, such as hurricanes.

The advantages of an synthetic aperture system over a real aperture system are significant. For example, error budget calculations based on simulations indicate that a synthetic aperture system can be expanded in size without unduly stressing the phase stability requirements. It is therefore well suited to meet future needs as the spatial resolution of numerical weather prediction models increase. Another advantage is that the GeoSTAR system does not require platform-disturbing mechanical scanning, and there is no time lag between different portions of the images, as there is in mechanically scanned real-aperture systems – where there can be a time lag of as much as an hour between the start of scan at the northern limit of the Earth disk and the end of scan at the southern limit. GeoSTAR thus produces true synoptic soundings; no other sounder has that capability. An additional advantage is fault tolerance. It is easy to add redundancy in the correlator system. Also, if one receiver should fail, the result is simply a slight degradation in image detail – there are no gaps in the image. (The reader can easily verify that by considering the effect of removing one receiver in Fig. 2.) This "graceful degradation" is in sharp contrast with the catastrophic failure modes of a conventional system, where the loss of one receiver will cause the loss of an entire sounding band.

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